Transmission Lines for High Frequency and High Density Packaging

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Abstract

We report on resistivity and chemical stability of Cr/Au bilayers deposited by sputtering on three kinds of substrates: alumina, aluminum nitride and aluminum nitride coated alumina. The insertion loss of Cr/Au microstrip lines fabricated on these three substrates was low and stable after 700 cycles in the -65°C to 125°C temperature range.

Introduction

Current and future missions at JPL and NASA require advanced high-frequency high-density packaging to decrease spacecraft mass and thus reduce launch vehicle size; with the goal of substantially reducing missions cost [1 ,2] As part of this initiative we have pioneered the development of a new concept for microwave/ millimeter-wave packages [Fig, 1], This package has excellent wide band low-loss input/output transitions which allows assembly tolerance to be relaxed; thereby decreasing cost, It is applicable to packaging of a single device as well as MCM's. The development of transmission lines for this new type of package is the subject of this paper.

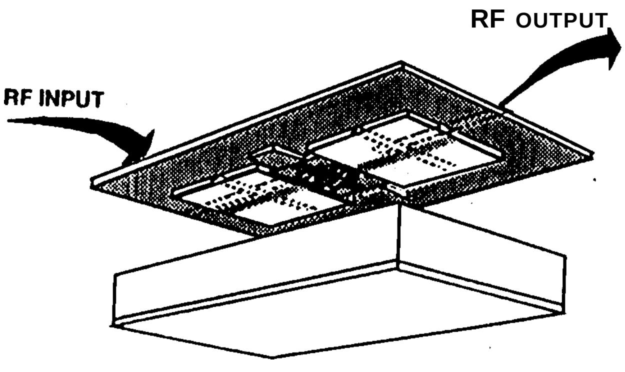

Fig 1. New manufacturable millimeter-wave ceramic package. Substrates employed in this application should have low RF loss, heat spreading capability, and be readily manufacturable.

Microwave and millimeter-wave transmission lines are required for device interconnection and signal flow control (bandpass filters, couplers, etc.). The objective of this work is to investigate the material parameters which affect high frequency transmission lines, Considerations for selecting a substrate material include thermal management, manufacturability (cost) as well as low RF loss performance,

Polished alumina substrates which have excellent RF properties are traditionally used in most microwave and millimeter-wave applications, With the need for high density multichip module packaging, alumina's poor thermal characteristics makes it less desirable. Aluminum nitride has excellent thermal conductivity and its coefficient of thermal expansion is closely matched to GaAs and Si devices. However, until only very recently the surface roughness of commercially available substrates were very poor (~3 pinch roughness for best substrates) resulting in high insertion loss [3], In order to take advantage of the thermal qualities of AIN and the electrical performance combined with surface smoothness of alumina, we investigated the development of thin film AIN on polished alumina substrates,

We used Cr/Au bilayers to fabricate microstrip lines metallization. Thin layer of Cr acted as the adhesion layer between Au and AIN or alumina, Upon thermal treatment, even at relatively low temperatures, chromium atoms diffuse to the gold layer causing an increase in the film's resistivity [4-8] presumably affecting the high frequency performance of the microstrip line, In this paper we report the effects of the high temperature annealing as well as thermal cycling on the stability, resistivity and insertion loss of the Cr/Au microstrip lines deposited on aluminum oxide, aluminum nitride, and alumina/thin film aluminum nitride substrates.

Experimental Procedure

Commercial ceramic substrates of alumina and aluminum nitride with surface roughness of about 1µinch and 3 µinch, respectively, were used in this experiment.

Thin films of AIN were deposited on alumina using RF magnetron reactive sputtering of the Al target (3 inch diameter) in the argon and nitrogen gas mixture. The alumina substrates were cleaned in ultrasonic baths of TCE, acetone, and methanol and then etched in the HF solution followed by a rinse in deionized water and dried in nitrogen. The etching in HF was an important step in achieving a good adhesion of AIN film to alumina. After loading the substrates into the sputtering chamber, the system was evacuated to a base pressure of about 3x1 O-7 Torr using a cryopump. The substrates were not heated nor cooled externally during the deposition process. The flow ratios of argon to nitrogen and total gas pressure were adjusted by mass flow controllers and monitored with a capacitive manometer in a feedback loop. The composition of AIN films were measured using Rutherford backscattering spectrometry of samples deposited on carbon substrates at different partial pressures of nitrogen. The stochiometric AIN were obtained using 40% of nitrogen and 10 mTorr total gas pressure. The density of the stoichiometric AIN films based on the thickness measurements using profilometer and Backscattering spectrometry was which is close to the bulk density of AIN.

The Cr and Au thin films were deposited using RF magnetron sputtering without breaking vacuum between depositions, The thickness of Cr layer was about 10 nm and the thickness of Au was 3.7 µm. The microstrip lines were fabricated using photolithography and etching, The thermal cycling was performed in nitrogen (-65°C to 125°C) according to MIL STD883 procedures, Simple wideband swept frequency insertion loss and return loss measurement were made using a vector network analyzer (which was calibrated with a TRL technique using alumina standards). In order to determine meaningful results we also measured a 50 ohm alumina microstrip transmission line with similar physical length for comparison,

The samples chosen for RBS analysis and sheet resistance measurements were 50 nm Cr and 240 nm Au bilayers. They were annealed in vacuum (3x1 O-7 Torr) for 30 min in the 200°C to 400°C temperature range.

Results and Conclusions

Figure 2 shows the ratio of sheet resistance of the Cr/Au bilayers deposited on bulk AIN substrate as a function of annealing temperature.

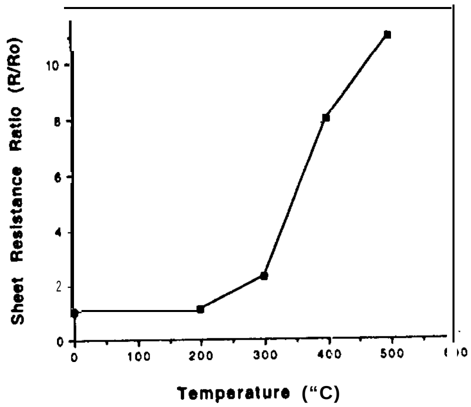

Fig. 2. The ratios of sheet resistance values (measured from four-point probe) are plotted as a function of annealing temperature for chromium/gold bilayers deposited on AIN,

After annealing at 200°C the sheet resistance ratio increased very slightly and became more noticeable after annealing at 300°C. The 400°C and 500°C annealing produced an order of magnitude change in the sheet resistance. The sheet resistance data are very consistent with RBS data, Figure 3 shows the RBS spectrum of the Cr/Au bilayer deposited on AIN before and after annealing at 200°C and 400"C.

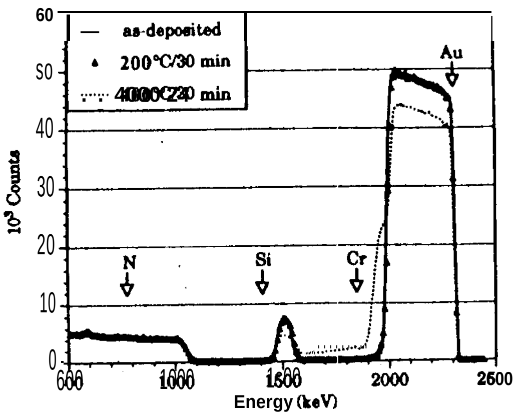

Fig.3. Backscattering spectra of as deposited and vacuum-annealed chromium/gold bilayers deposited on AIN.

After annealing at 200°C a slight interdiffusion can be observed between Cr and Au. After annealing at 400°C a massive inter-diffusion between Au and Cr is observed. Cr atoms diffuse to the surface of Au where they form thin layer of chromium oxide. The presence of this layer can have deleterious effects on the performance of the transmission lines at high frequencies due to skin effect, The same behavior of Cr/Au bilayers was observed in samples deposited on alumina and oxidized silicon [8],

In order to determine the relationship between the thickness of the AIN layer and its heat spreading capability, we performed a thermal analysis of a package shown in Fig.1. The results of this thermal analysis are presented in Fig.4.

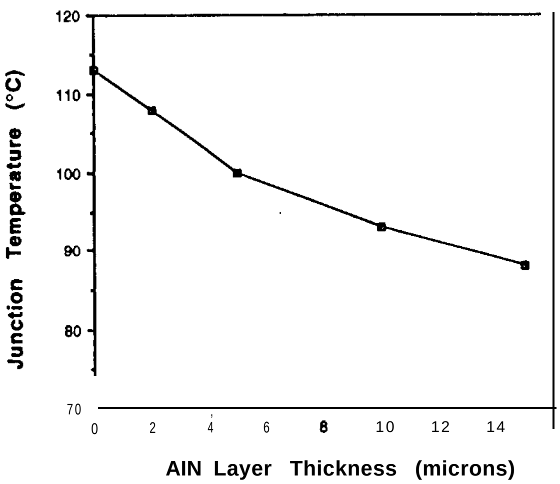

Fig.4. Simulation of the junction temperature of a 0.5W MMIC on an alumina substrate with the thin film AIN heat spreader.

It is concluded that the 10 µm thick film of AIN will have high enough thermal conductivity to keep a 0.5 W (20% PAE) SSPA MMIC chip at a maximum junction temperature of 11 O" which meets MIL STD 883 requirements, On that basis we chose a 10 µm AIN thin film for the high frequency characterization.

In Figures 5, 6, and 7 we compare commercial bulk AIN (3 µinch surface roughness), thin film AIN on alumina, and alumina control lines for insertion loss and return loss, respectively. We subjected all three samples to thermal cycling in order to determine the impact of thermal fatigue on the high frequency performance of the microstrip lines. An important result of this work is that the electrical parameters did not change over 100 temperature cycles from -65°C to 125°C following MIL STD 883. The insertion loss of the AIN thin film is only 0.3 dB worse than the polished alumina standard at 30 GHz (worst case). Experimental error of our measurements is 0.02 dB. The return loss is primarily limited by the test fixture used. Since a simple TRL calibration is used, the coaxial launch is not completely deembeded.

We have shown that this multilayer approach for millimeter wave packages is very promising. The advantage of using AIN thin film instead of a bulk AIN ceramic arises from the fact that, using simple patterning techniques, the thin film can be deposited selectively only at places in the package where thermal performance is critical whereas uncoated alumina can be left at places where electrical performance is more important than thermal.

Acknowledgments

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References

[1] M. Herman, K. Lee, L. Lowry, E. Kolawa, and A. Tulintseff, IEEE MTT (submitted).

[2] M. Herman, K. Lee, L. Lowry, A. Carpenter, and P. Wamhof, NASA Tech Briefs, June 1994, p.24.

[3] H. Sobol, Proc. IEEE, 59,1200 (1971),

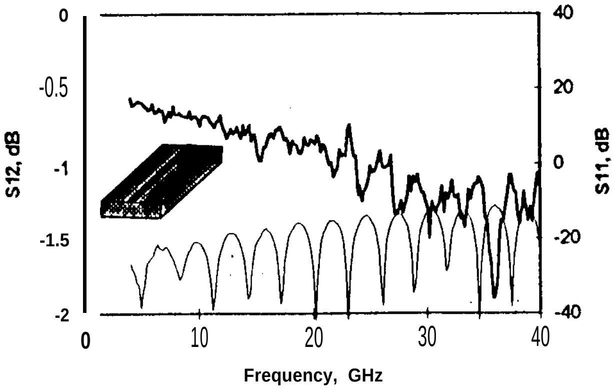
[4] V. Schwartz and R.W. Berry, Phys. Thin Films 2, 363 (1964).

[5] M. Mattox, Thin Solid Films, 18, 173 (1973).

[6] J.R. Rairden, C.A. Neugebauer, and R.A. Sigsbee, Metall. Trans., 2,719(1971).

[7] R. E. Thomas, G.A. Haas, J. Appl. Phys., 43, 4900 (1 972).

[8] D.Y.C. Lie, E. Kolawa, R. De Angelis, L. Lowry, and J. Scott-Monck, in Proc. of Advanced Metallization for ULSI Applications Conf., Materials Research Society, San Diego, p.583 (1993).



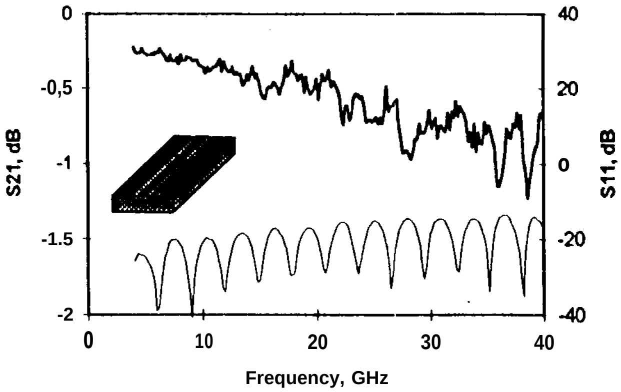
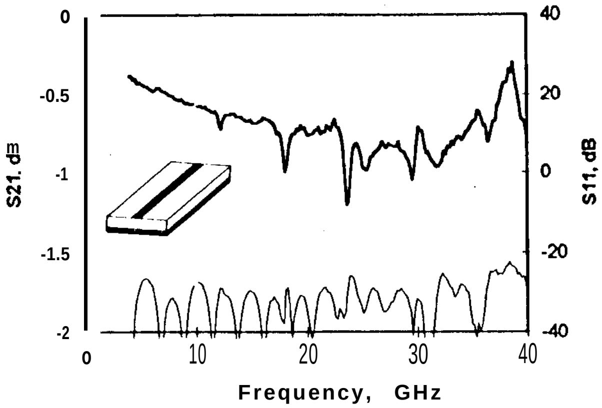


Fig.5. Measured insertion and return loss of a 50 Ohm transmission line fabricated on a bulk aluminum nitride substrate 2.54 cm long, 0.0254 cm thick **a)as** deposited.

b) after 100 thermal cycles.



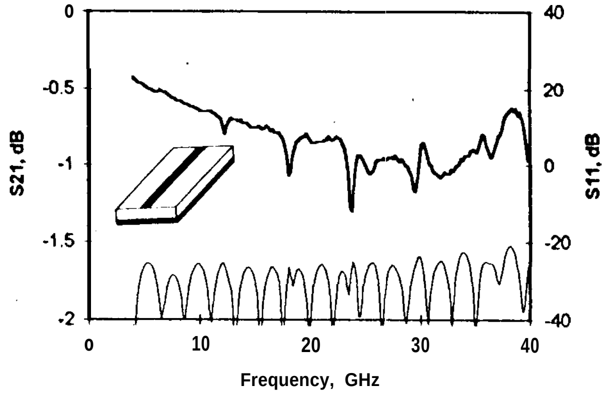
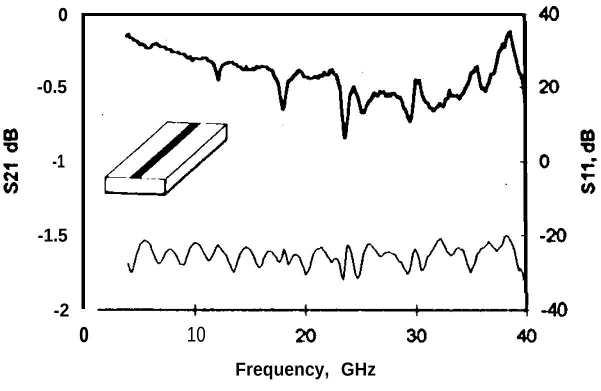


Fig.6. Measured insertion and return loss of a 50 Ohm transmission line fabricated on **multilayer** thin film AIN (1 O **µm)on** alumina substrate 2.54 cm long, 0.0254 **cm** thick **a)as** deposited,

b) after 100 thermal cycles,



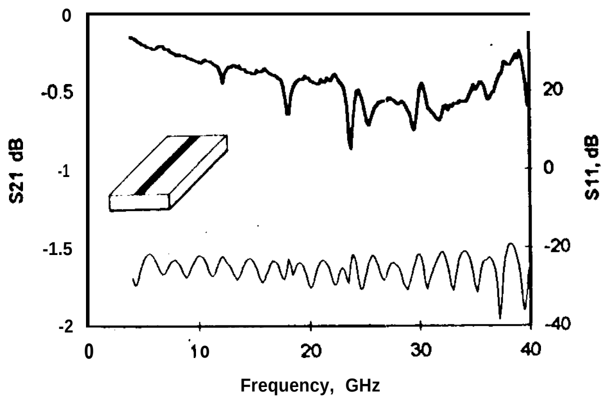


Fig.7. Measured insertion and return loss of a 50 Ohm transmission line fabricated on a bulk alumina substrate 2.54 cm long, 0.0254 cm thick **a)as** deposited.

b) after 100 thermal cycles.